

Parameterizing Gravity Drainage for Models of Sea Ice Passive Tracers and Salinity

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This Talk

- How I came to develop a sea ice tracer model: biogeochemistry
- Gravity drainage in a tracer model: IceT, 2 ways
- Is there a preference?
- Gravity drainage in a salinity model: IceT^{-I}, 2 ways
- A clear winner?
- Conclusions

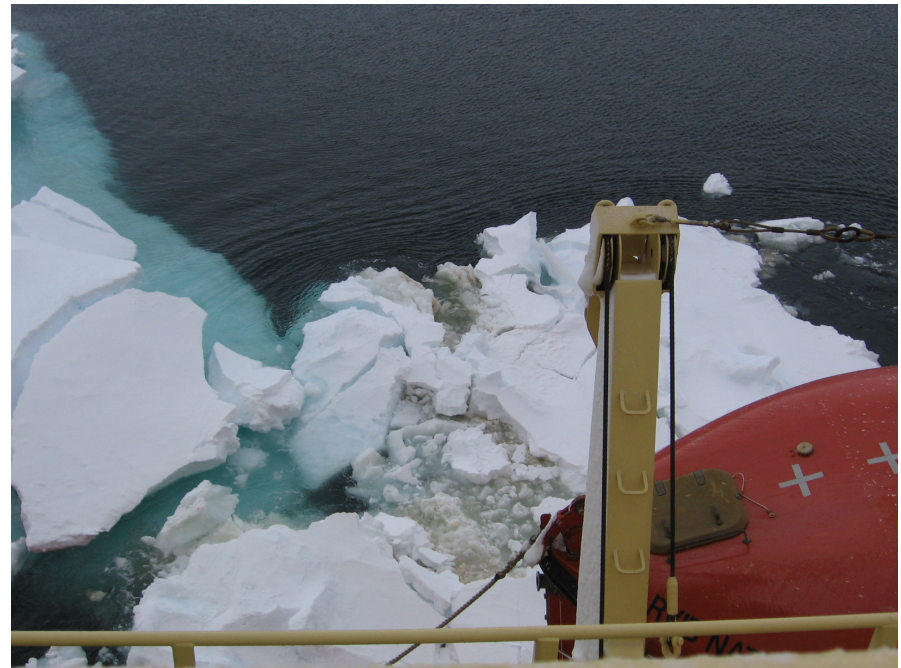
Modeling the Physics Sea Ice Biogeochemistry

Things of concern...

- In brine tracer concentrations of Nutrients – “passive tracers”
- Ocean/ice fluxes, fluxes from surface flooding and flushing
- Light (PAR) with depth
- Sea Ice Microphysics

Things not of concern...

- Don't need to Improve CICE model
- Don't need to solve for $T(z,t)$ and $S(z,t)$. Assume knowledge of T and S from model output or data



Richard Cullather Antarctic sea ice

Approach

- $T(z,t)$ and $S(z,t)$ define the “averaged” microstructure:
brine averaged ρ_b , S_b , ϕ , Π
- Microstructure + gravity \rightarrow Brine motion
- Passive tracers differ from S (active tracer) in that they move/mix with the brine but do not effect the motion
- However, a passive scalar without chemistry should evolve as salinity, if the evolution of ϕ is known.

Develop gravity drainage parameterization while avoiding conceptually challenging complications...

\rightarrow The microstructure drives desalination which in turn modifies the microstructure

Tracer transport in sea ice for large scale models: “volume averaging”

Brine/intrinsic average

$$[c] = \frac{1}{\mathcal{V}_b} \int_{\mathcal{V}_b} c dV$$

Bulk average

$$\langle c \rangle = \frac{1}{\mathcal{V}} \int_{\mathcal{V}_b} c dV$$

- Continuity
- Stokes flow → Darcy's eqn.

$$\langle w \rangle = -\frac{\Pi}{\mu} \left(\frac{\partial [P]}{\partial z} + \rho g \right)$$

- Advection-diffusion for passive tracer
 - Terms appear which characterize the averaged microstructure: porosity ϕ , permeability Π
 - And terms appear which need closing...

$$\langle \tilde{c} \tilde{w} \rangle$$

IceT

Darcy Velocity (flushing and flooding) ↓

Molecular diffusion

$$\phi \frac{\partial [c]}{\partial t} + \frac{\partial ([c] \langle w \rangle)}{\partial z} + \frac{\partial \langle \tilde{c} \tilde{w} \rangle}{\partial z} = \frac{\partial}{\partial z} \left(\phi \overset{\downarrow}{D_m} \frac{\partial [c]}{\partial z} \right)$$

↑ Gravity Drainage

Reynolds flux closure: $\langle \tilde{c} \tilde{w} \rangle = -D \frac{\partial}{\partial z} [c]$

Propose two parameterizations for the “Eddy” diffusivity:

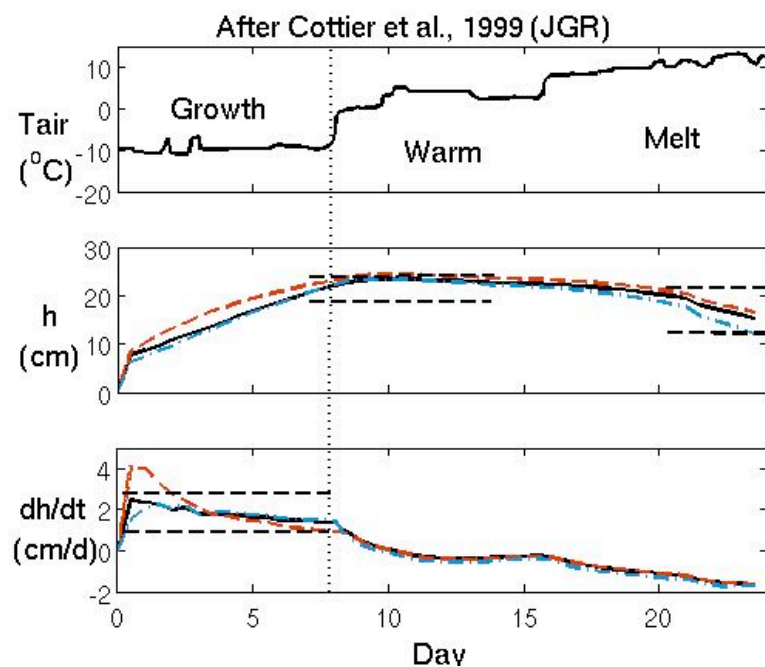
Mixing Length Diffusivity
(MLD)

$$D_{ml} = \begin{cases} \frac{g \Pi_o}{\mu} \phi^3 \Delta \rho_b l & \text{if } \rho_b(z) \text{ is unstable} \\ 0 & \text{otherwise} \end{cases}$$

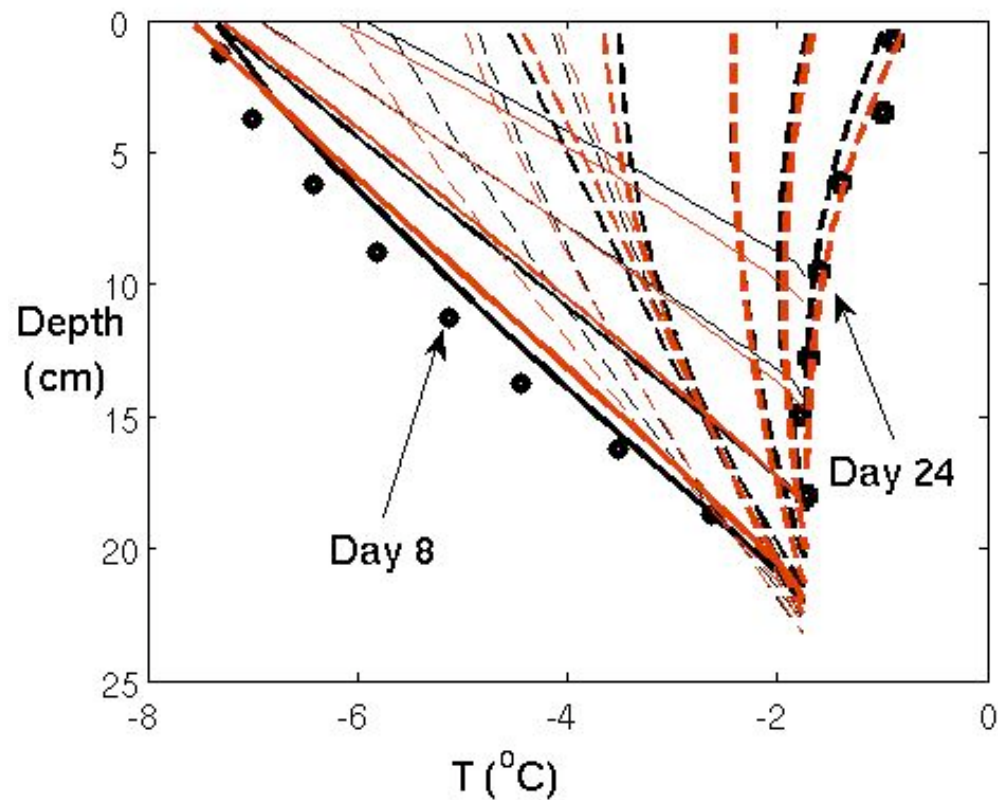
Enhanced Molecular Diffusivity
(EMD)

$$D_e = \begin{cases} \phi \mathcal{D}_e & \text{if } \frac{dh}{dt} > 0 \\ 0 & \text{otherwise} \end{cases}$$

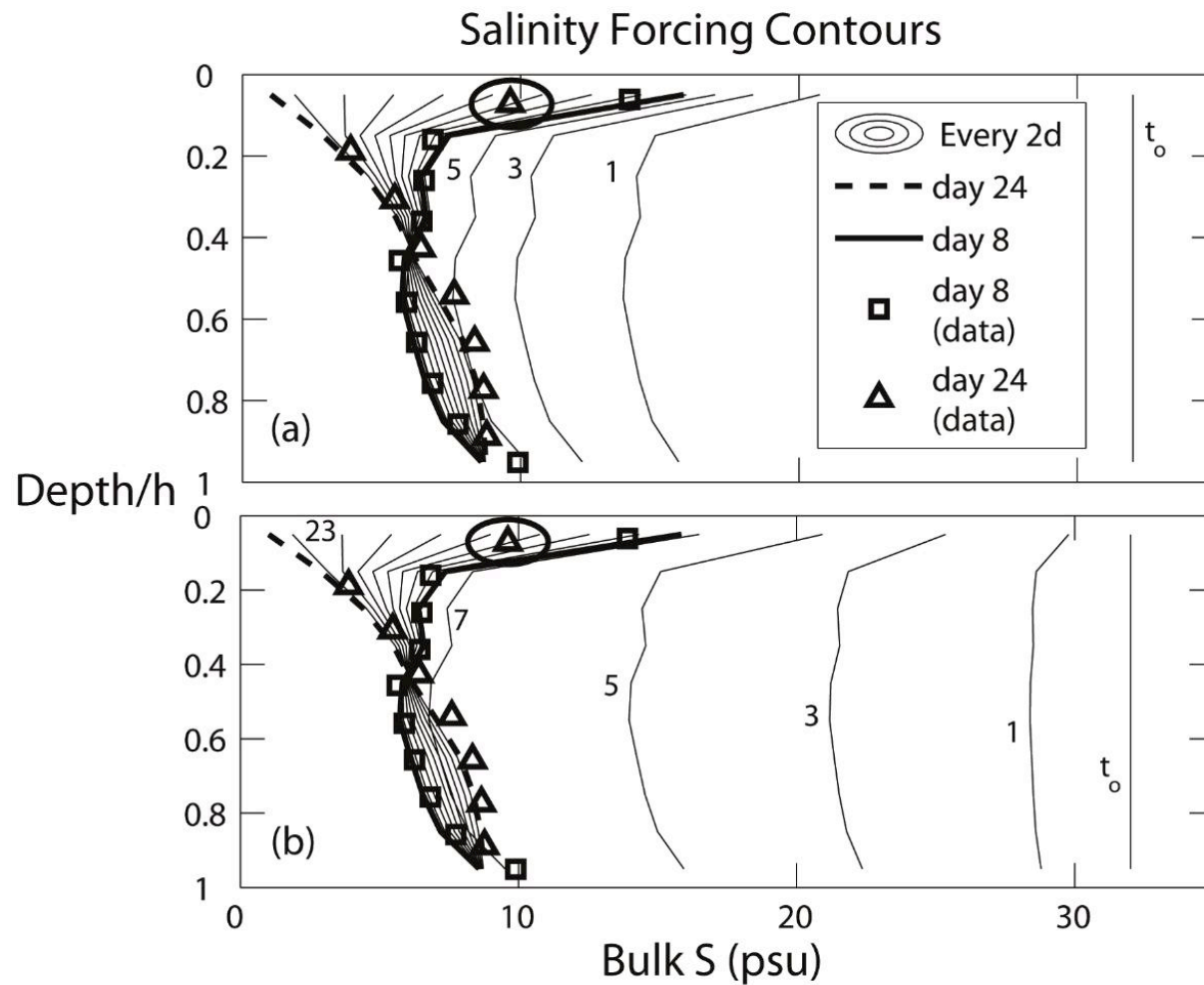
CICE as a Sophisticated Interpolator



Sea Ice $T(z,t)$
2 different salinity evolutions

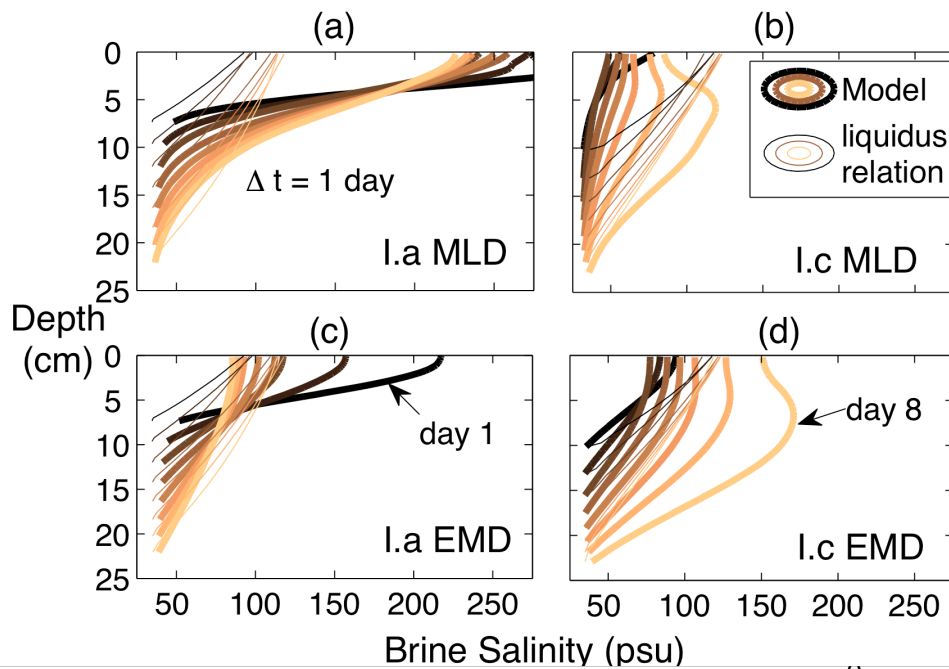


Me as a less sophisticated Interpolator



IceT solutions of [c] compared with brine salinity

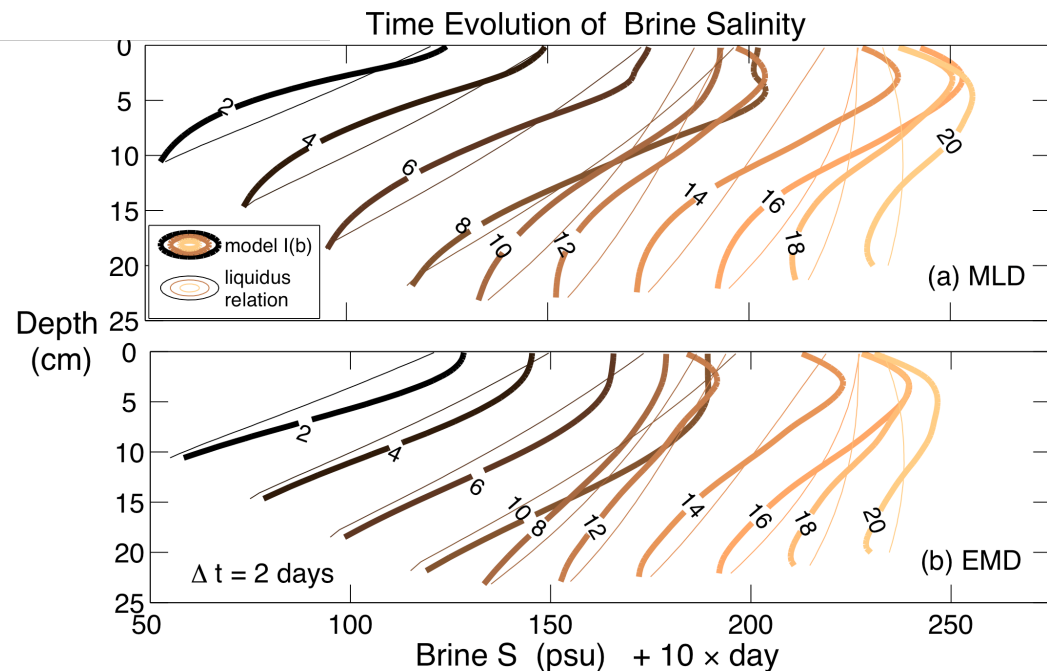
I.a fixed 'C' S-profile
 ← I.b linear decrease to 'C'

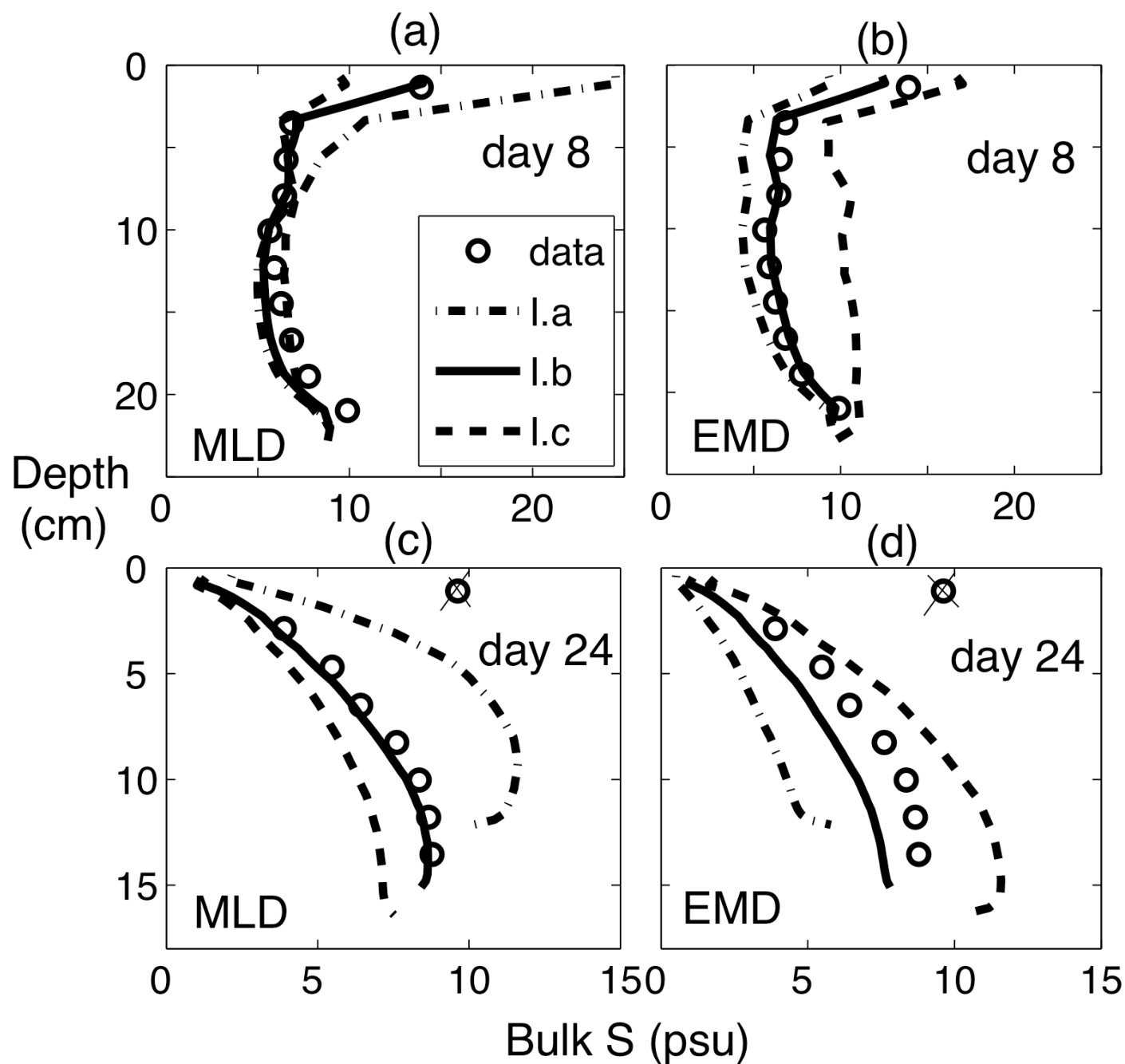


$$\text{MLD} \sim \Delta \rho_b \phi^3$$

$$\text{EMD} \sim \phi$$

Logarithmic decrease to 'C'
 S-profile →





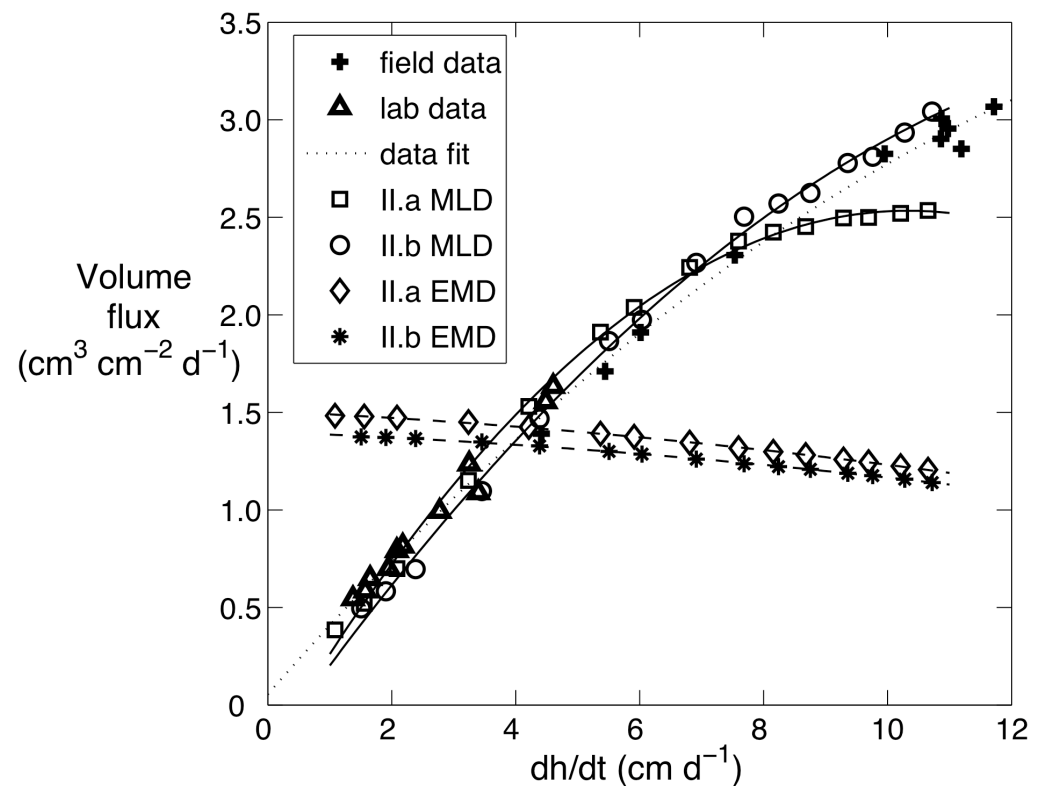
IceT solutions
[c] ϕ compared
with bulk S

l.a fixed C
l.b log decrease
to 'C'
l.c linear decrease
to 'C'

MLD vs. EMD

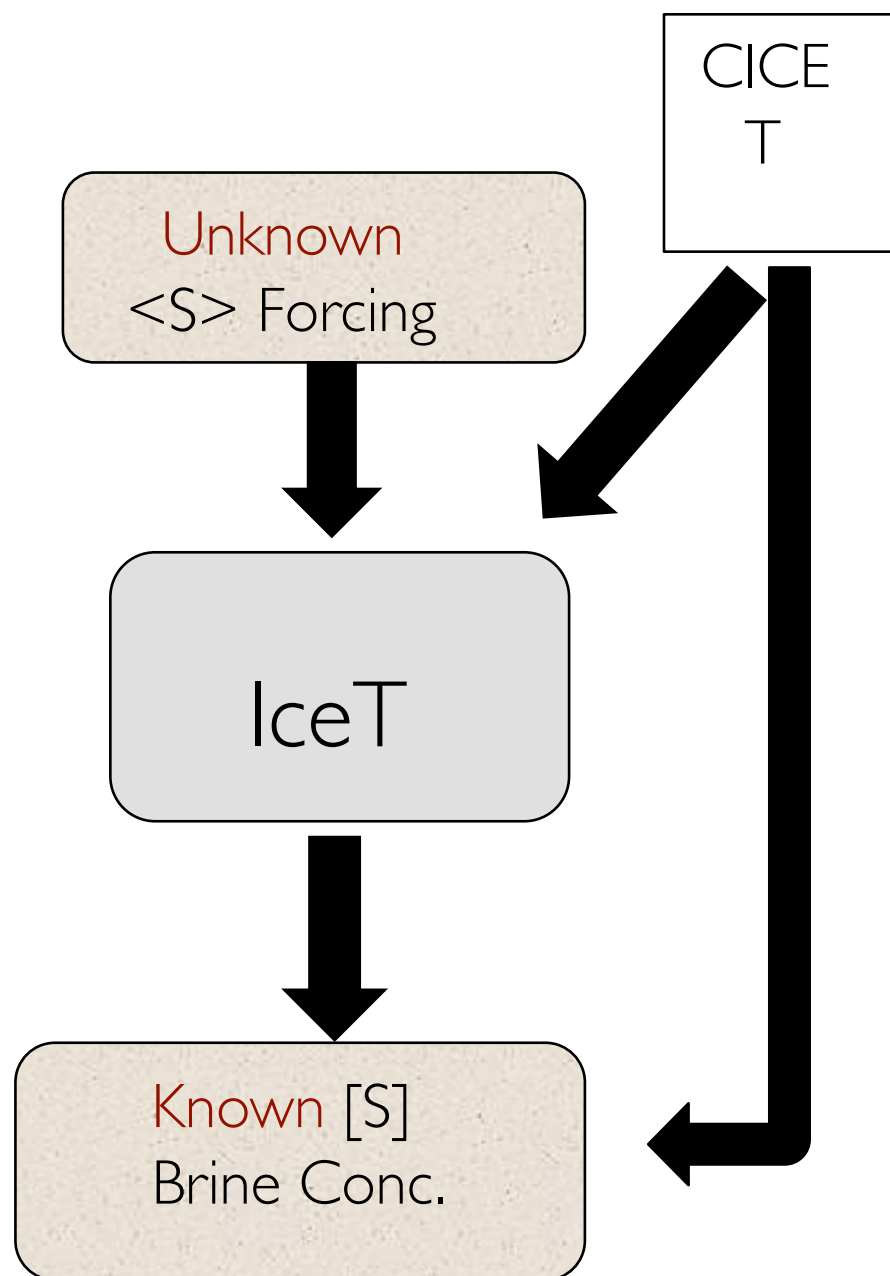
After the Cottier et al. test problem, no clear preference.

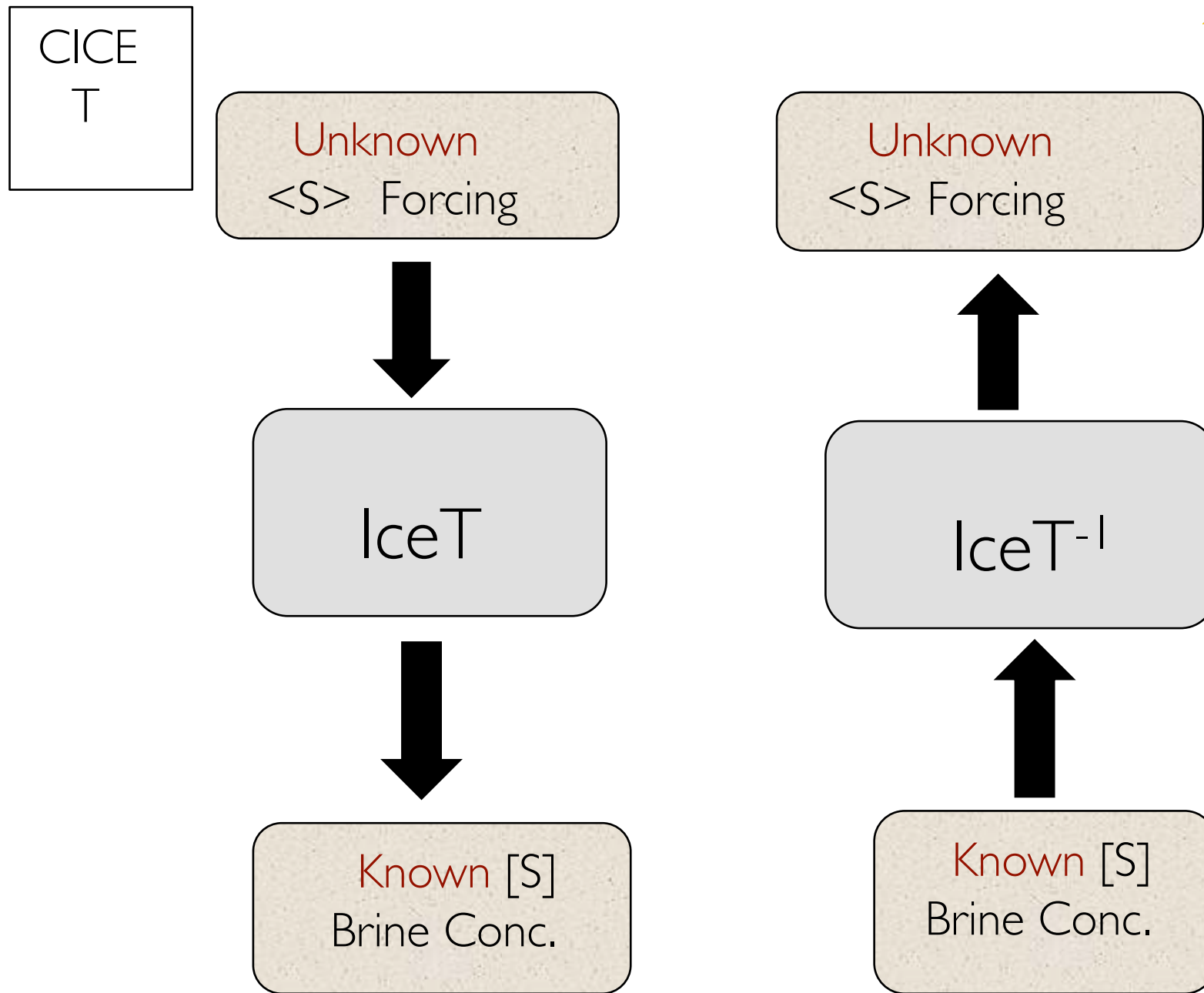
- Some indications that EMD parameterization could fail in the salinity problem...
- Measurements of brine volume flux at the ice/water boundary increase with $dh/dt \sim \text{MLD}$
- A Reynolds closure does the job.

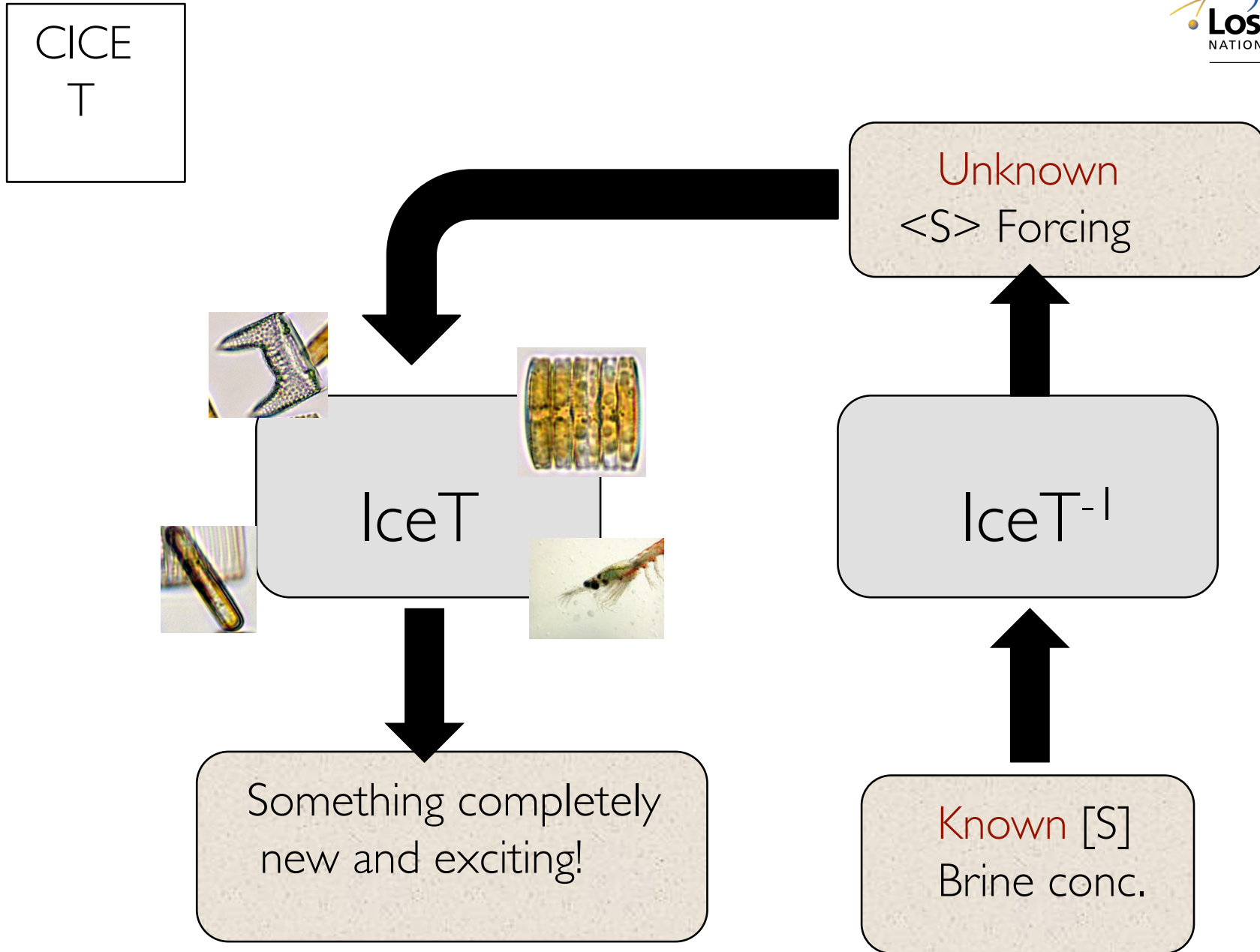


Data from Wakatsuchi and Ono, 1983

The problem: to get the answer
I need the answer.







IceT⁻¹

Volume average continuity....

$$\left\langle \frac{\partial \rho}{\partial t} + \partial_i(\rho u_i) \right\rangle = 0$$

$$\frac{\partial[\phi(\rho_b - \rho_i)]}{\partial t} + \frac{\partial(\rho_b \langle w \rangle)}{\partial z} + \frac{\partial \langle \tilde{\rho} \tilde{w} \rangle}{\partial z} = 0$$

Brine density (ρ_b), ice density (ρ_i), Bulk velocity ($\langle w \rangle$), porosity (ϕ)

IceT⁻¹ MLD

Parameters depend on T, dh/dt, h

$$\frac{\partial \langle S \rangle}{\partial t} = W_b \frac{\partial \langle S \rangle}{\partial z} + ((\rho_b - \rho_i)B(T))^{-1} \left\{ \frac{\partial(\mathcal{V}_{ml} \langle S \rangle^3)}{\partial z} + c \right\}$$

Boundary velocity

Gravity drainage

Flushing

$$\frac{\partial \langle S \rangle}{\partial t} = W_b \frac{\partial \langle S \rangle}{\partial z} + ((\rho_b - \rho_i)B(T))^{-1} \left\{ \frac{\partial(\mathcal{V}_e \langle S \rangle)}{\partial z} + c \right\}$$

IceT⁻¹ EMD

IceT⁻¹ MLD

Parameters depend on T, dh/dt, h

$$\frac{\partial \langle S \rangle}{\partial t} = W_b \frac{\partial \langle S \rangle}{\partial z} + ((\rho_b - \rho_i)B(T))^{-1} \left\{ \frac{\partial (\mathcal{V}_{ml} \langle S \rangle^3)}{\partial z} + \mathcal{C} \right\}$$

Boundary velocity

Gravity drainage

Flushing

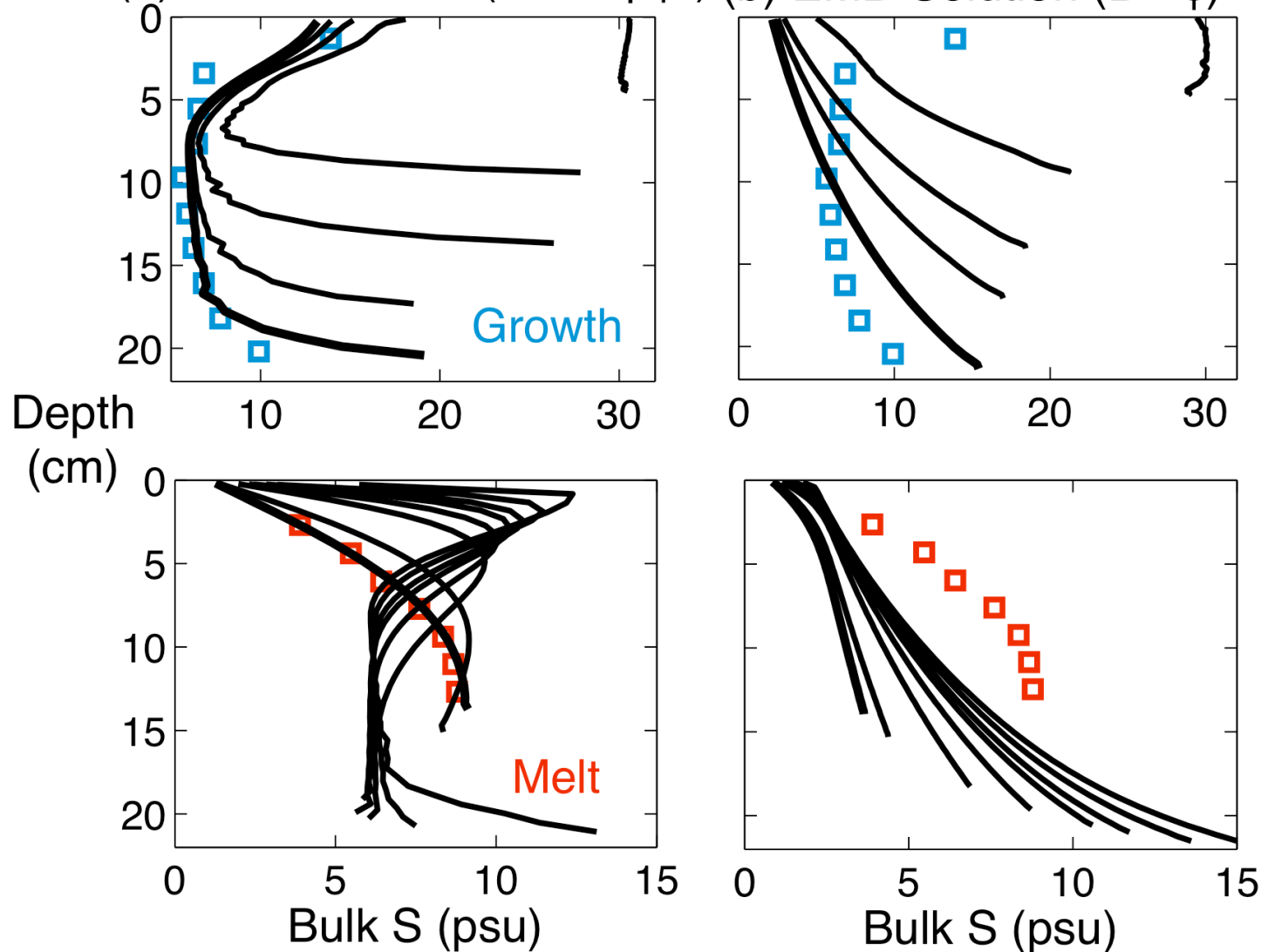
$$\frac{\partial [c]}{\partial t} = W_b \frac{\partial (\phi [c])}{\partial z} + \frac{\partial}{\partial z} \left(a \Delta \rho \phi^3 \frac{\partial [c]}{\partial z} \right) - \langle w \rangle \frac{\partial [c]}{\partial z}$$

IceT MLD

Parameters depend on T, dh/dt, h and $\langle S \rangle$

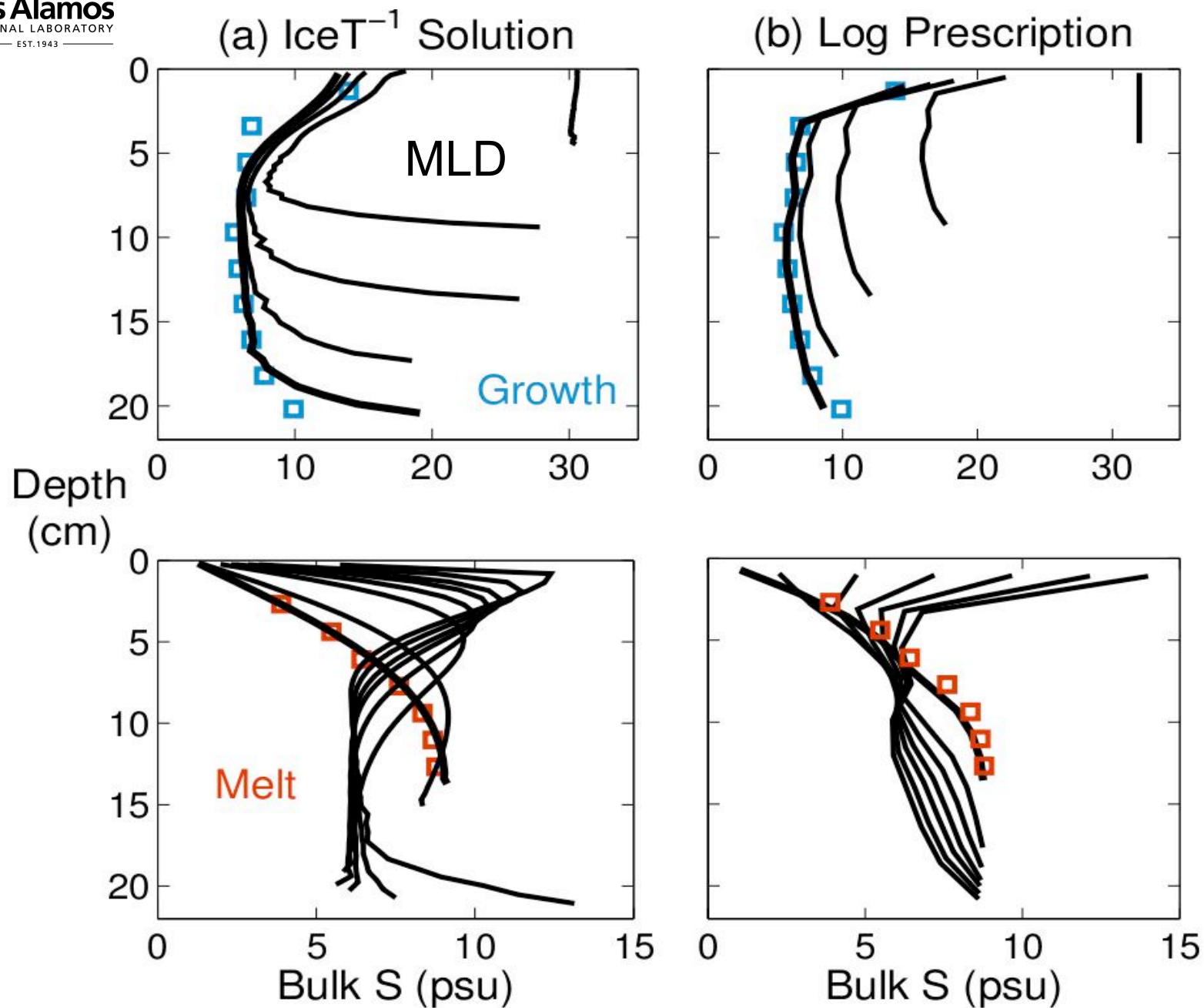
IceT⁻¹

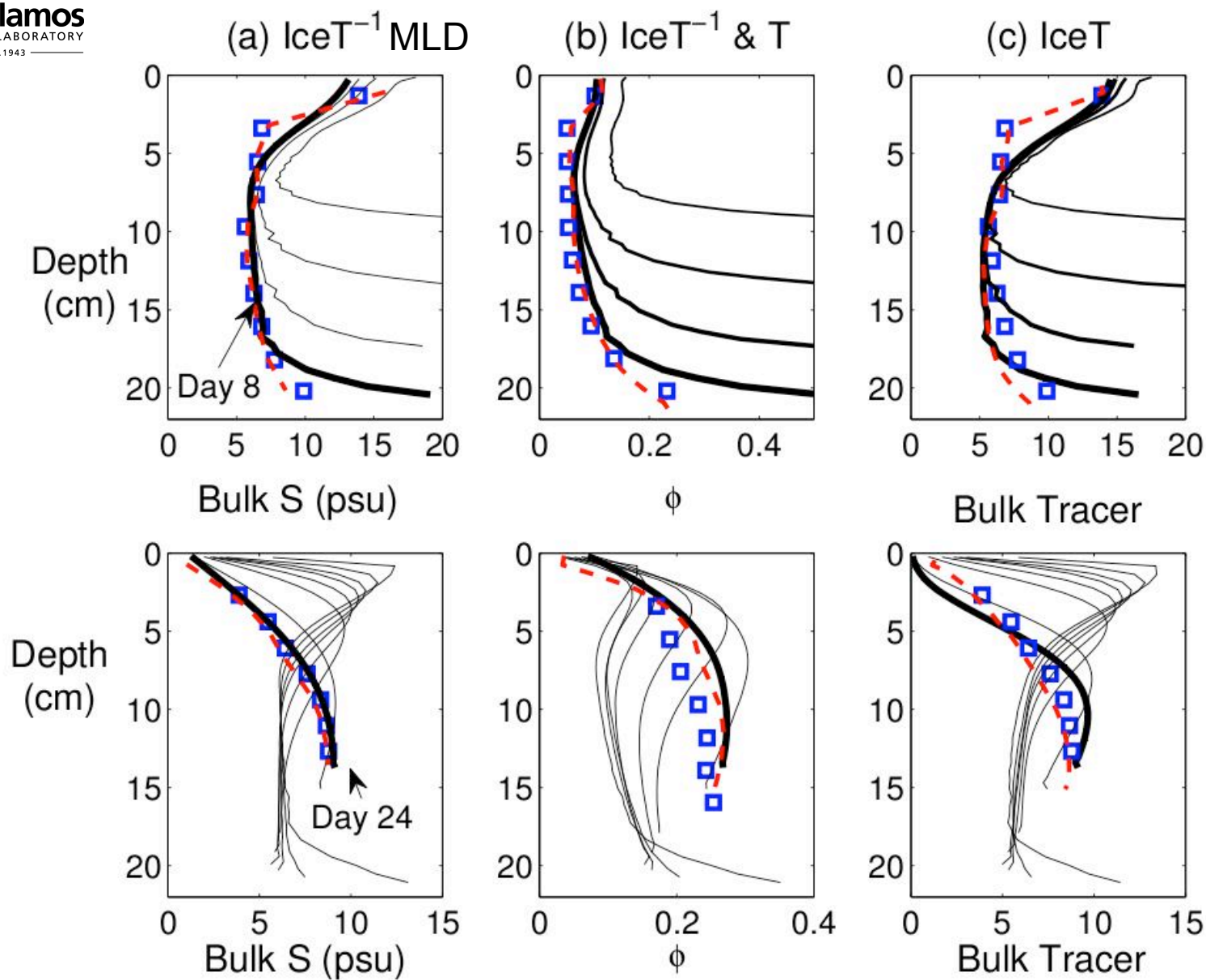
(a) MLD Solution ($D \sim \Delta \rho \phi^3$) (b) EMD Solution ($D \sim \phi$)



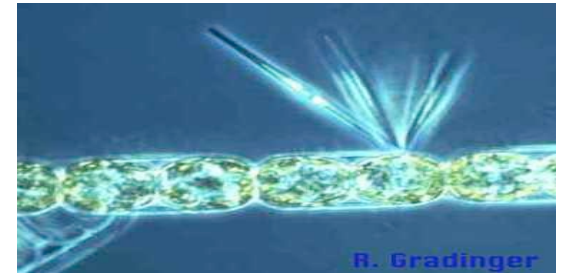
- MLD solution traps salt in the upper ice

- EMD does not contain Π information.





Conclusions



- Passive tracer problem is conceptually simpler. Gravity drainage velocity-tracer fluctuations may be parameterized using a Reynolds flux closure.
- Passive tracer problem is less sensitive to the form of the diffusivity (both EMD and MLD work well for some problems), however knowledge of S is required.
- Solution of bulk salinity comes from the inverse model. Diffusion becomes a (non)linear advection term.
- EMD does not have adequate sensitivity to model gravity drainage, however MLD is promising.
- With current CICE output (T , dh/dt , h), we can solve for S and passive tracer brine concentration.
- 2-way coupling with CICE through T_{mlt} and K works but hasn't been fully tested.